UNIVERSITI PUTRA MALAYSIA

FORAGING OF COPTOTERMES CURVIGNATHUS (INSECTA: ISOPTERA: RHINOTERMITIDAE) AND PATTERN OF DAMAGE IN OIL PALM ON PEAT IN BINTULU SARAWAK

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By

CHAN SEOW PHAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

FORAGING OF *COPTOTERMES CURVIGNATHUS* (INSECTA: ISOPTERA: RHINOTERMITIDAE) AND PATTERN OF DAMAGE IN OIL PALM ON PEAT IN BINTULU SARAWAK

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December 2012

Chairman: Joseph Bong Choon Fah, PhD

Faculty: Agriculture and Food Sciences, Bintulu

Coptotermes curvignathus is a major pest in oil palm plantation planted on peat. The control of the pest was unsatisfactory due to its lifestyle that made the observation on its foraging behaviour difficult. The objectives of this study were to verify the identity of the pest, to determine the tunnelling activity of *C. curvignathus* towards presence and absence of food source in the laboratory, to detect the presence and absence of *C. curvignathus* surrounding an infested palm and lastly to investigate the damage pattern and infestation in oil palm. Tunnelling arena with and without food was prepared to compare the distribution of tunnel length and frequency of tunnel initiation in all direction to see whether any directional feeding occurred. Field study using underground baiting station with rubber wood arranged in all direction was set up surrounding an infested palm to detect the presence or absence

of *C. curvignathus*. Infested oil palms were dissected to see the interior damage caused by *C. curvignathus*, while survey of the infestation rate was carried out to determine its pattern of infestation. Morphological and molecular studies have verified the termite species as *C. curvignathus* with 99-100% similarity between 2-403 bp from the reference samples. The initial tunnelling activity of *C. curvignathus* was random but food oriented. This was due to insignificant distribution of tunnelling activity and tunnel initiation in no food arena but presence of food induced higher tunnelling activity and higher amount of tunnel initiated. Higher tunnel length was found (234.53 mm) in food present arena compared to no food arena (156.00 mm). The distribution of tunnelling activity in food present arena was not uniform as North sector (335.68 mm) possessed significant higher tunnel length than East (176.55 mm), Southwest (212.76 mm), West (185.24 mm) and Northwest (187.15 mm) respectively. Although the distribution of tunnel initiation was random, it was more likely for *C. curvignathus* to search in North sector as indicated in the present study. The significant difference of tunnel distribution in certain sector was also due to the search behaviour of the termite whenever food source was encountered. *Coptotermes curvignathus* tend to branch if the primary tunnel managed to encounter food source while long primary tunnel was excavated if no food were discovered. This observation was supported by significant differences in length of exploratory tunnels (1420. 8 mm) compared to secondary tunnels (351.8 mm) in food present arena. In the food absent arena, primary tunnels significantly dominated with tunnel length of 700.7 mm compared to secondary tunnels (280.6 mm). *Coptotermes curvignathus* was also observed not visiting all available food sources in the arena and thus, skewed the tunnel distribution in certain sector. Field study revealed that *C. curvignathus* was scattered surrounding an infested palm. It was a dominant termite species in peat as no other termite species was found within a baiting station occupied by *C. curvignathus*. Similarly to the laboratory observation, not all baiting station was found infested at any one time during the assessment period. *Coptotermes curvignathus* damaged the oil palm by excavation and eventually chambers were formed inside the trunk. Thin laminae structures were found within these chambers. Each structure had different thickness (0.98-2.27 mm) and shapes (cell height 3.54-8.92 mm, cell width 6.54-16.82 mm). This constructed structure was believed to be its endoecie where alates and nymphs were found. However the availability of thin laminae structure was random among the infested palm. The infestation incidences of oil palm were found to fluctuate throughout the year. Total infestation incidence ranged from 0.02 to 0.11%. Among the infested palms, about 11.7-23.9% had damage through spear region infestation. There was no evidence of basal infestation during the assessment period. The pattern of infestation was not influenced by monthly rainfall since no significant relationship was established. Regular chemical control managed to keep infestation low but the infestation persisted throughout the years in the surveyed plantations.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENCARIAN MAKANAN OLEH *COPTOTERMES CURVIGNATHUS* (INSECTA: ISOPTERA: RHINOTERMITIDAE) DAN CORAK KEROSAKAN PADA KELAPA SAWIT DI TANAH GAMBUT DI BINTULU SARAWAK

Oleh

CHAN SEOW PHAN

December 2012

Pengerusi: Joseph Bong Choon Fah, PhD

Fakulti: Sains Pertanian dan Makanan, Bintulu

Coptotermes curvignathus adalah perosak utama di ladang kelapa sawit yang ditanam di tanah gambut. Kawalan perosak anai-anai adalah tidak memuaskan disebabkan oleh gaya hidupnya yang menyusahkan permerhatian terhadap kelakuan pencarian makanannya. Objektif kajian ini adalah untuk mengesahkan identiti perosak, menentukan aktiviti menerowong *C. curvignathus* di kawasan dengan dan tanpa sumber makanan di dalam makmal, mengesan kehadiran dan ketiadaan *C. curvignathus* di sekitar kelapa sawit yang diserang, dan untuk menyiasat corak kerosakan dan serangan pada kelapa sawit. Arena terowong dengan dan tanpa makanan disediakan untuk membandingkan taburan panjang terowong dan kekerapan permulaan terowong dalam semua arah untuk melihat samaada berlakunya pemakanan berarah. Kerja lapangan menggunakan stesen umpan dengan

kayu getah disediakan di sekitar kelapa sawit yang diserang untuk mengesan taburan *C. curvignathus*. Kelapa sawit dibedah untuk melihat kerosakan dalaman akibat serangan *C. curvignathus*, manakala survei kerosakan dijalankan untuk menentukan corak serangan anai-anai. Kajian morfologi dan molekul mengesahkan spesis anai-anai sebagai *C. curvignathus* dengan persamaan 99-100% antara 2-403 bp daripada sampel rujukan. Permulaan terowong *C. curvignathus* adalah rawak tetapi dipengaruhi oleh makanan. Ini adalah disebabkan oleh taburan terowong dan permulaan terowong yang tidak ketara dalam kawasan terowong tanpa makana tetapi kehadiran makanan menyebabkan aktiviti terowong dan jumlah permulaan terowong yang lebih tinggi terowong. Kawasan terowong bermakanan mempunyai panjang terowong yang lebih tinggi (234.53 mm) berbanding dengan kawasan terowong tanpa makanan (156.00 mm). Taburan activiti terowong dalam kawasan bermakanan adalah tidak seragam kerana sektor Utara (335.68 mm) memiliki panjang terowong yang lebih ketara daripada Timur (176.55 mm), Barat Daya (212.76 mm), Barat (185.24 mm) dan Barat laut (187.15 mm). Walaupun taburan permulaan terowong adalah rawak, *C. curvignathus* lebih cenderung untuk menerowong dalam sektor Utara seperti yang ditunjukkan dalam kajian ini. Perbezaan yang signifikan dalam taburan terowong dalam sektor tertentu juga disebabkan oleh tingkah laku pencarian anai-anai apabila sumber makanan telah dijumpai. Terowong *C. curvignathus* lebih cenderung untuk bercabang jika terowong utamanya berjaya menemui sumber dan sebaliknya jika makanan tidak ditemui. Pemerhatian ini disokong oleh perbezaan yang signifikan dalam panjang terowong penerokaan (1420.8 mm) berbanding terowong menengah (351.8 mm) dalam kawasan bermakanan. Dalam kawasan terowong tanpa makanan, terowong utama menguasai kawasan tersebut dengan panjang terowong 700.7 mm berbanding terowong menengah (280.6 mm). *Coptotermes curvignathus* telah juga didapati tidak melawati kesemua sumber makanan dalam kawasan terowong itu dan mangakibatkan pengagihan terowong dalam sektor tertentu. Kerja lapangan menunjukkan *C. curvignathus* adalah bertabur di sekitar kelapa sawit yang diserang. Ia adalah anai-anai yang dominan di tanah gambut dimana tiada spesis anai-anai yang lain telah ditemui dalam stesen umpan dimana *C. curvignathus* berada. *Coptotermes curvignathus* telah juga didapati tidak melawati kesemua stesen umpan pada satu-satu masa dalam tempoh penilaian. *Coptotermes curvignathus* merosakkan kelapa sawit dengan penggalian dan akhirnya mengakibatkan ruang dibentuk di dalam batang kalapa sawit. Struktur lamina nipis telah ditemui di dalam ruang ini. Setiap struktur lamina mempunyai ketebalan yang berbeza (0.98-2.27 mm) dan mempunyai berbagai bentuk (ketinggian sel 3.54-8.92 mm, kelebaran sel 6.54-16.82 mm). Struktur ini dipercayai adalah endoecienya kerana rayap dan nimfanya ditemui dalam struktur tersebut. Akan tetapi kehadiran struktur lamina ini adalah rawak. Kejadian serangan kelapa sawit didapati turun naik sepanjang tahun. Jumlah insiden serangan adalah diantara 0.02-0.11%. Antara kelapa sawit yang diserang, terdapat 11.7-23.9% mempunyai kerosakan melalui rantau lembing. Tiada bukti serangan bawah kelapa sawit didapati dalam tempoh penilaian. Corak serangan anai-anai adalah tidak dipengaruhi oleh jumlah hujan bulanan kerana tiada hubungan yang signifikan telah dijumpai. Kawalan kimia yang kerap berjaya memastikan serangan yang rendah tetapi serangan adalah berterusan sepanjang tahun di ladang-ladang yang dikaji.

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Kindness is the language which the deaf can hear and blind can see

(Mark Twain)

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I certify that a Thesis Examination Committee has met on (13 December 2012**)** to conduct the final examination of (Chan Seow Phan) on his thesis entitled "**Foraging of *Coptotermes curvignathus*** (Insecta: Isoptera: Rhinotermitidae) and Pattern of Damage in Oil Palm on Peat in Bintulu Sarawak" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the (Master of Science (Entomology)).

Members of the Thesis Examination Committee were as follows:

Japar Sidik bin Bujang, PhD
Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia
(Chairman)

Ahmad Said bin Sajap, PhD
Professor
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

Hadfizi bin Mohd Nor, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Idris bin Abdul Ghani, PhD
Professor
Faculty of Science and Technology
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis is submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. Members of the Supervisory Committee were as follows:

Joseph Bong Choon Fah, PhD
Associate Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia
Bintulu Sarawak Campus
(Chairman)

Lau Wei Hong, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Rajan a/l Amarthalingam, PhD
Associate Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia
Bintulu Sarawak Campus
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATIONS

I hereby declare that the thesis is based on my original work except for quotations and citation, which have been duly acknowledged. I also declare that it has not been previously or concurrent submitted for any degree at Universiti Putra Malaysia or other institutions.

CHAN SEOW PHAN

Date: 13 December 2012

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ha	Hectare
bp	basepair
e.g.	Example
mm	Millimetre
w/w	Weight per weight
%	Percent
min	Minute
cm	Centimetre
cm^3	Centimetre cube
m	metre
m^2	Meter square
Km	kilometre
mL	Millilitre
^oC	Degree Celcius
ANOVA	Analysis of Variance
DNA	Deoxy ribonucleic acid
PCR	Polymerase Chain Reaction
BLAST	Basic Local Alignment Search Tool

CHAPTER 1

INTRODUCTION

Malaysia is one of the leading producers of palm oil in the world with a total of 5.0 million ha planted nationwide (MPOB, 2011). The eastern states of Sabah and Sarawak in Malaysia were accounted for 49% of total area planted in the country (MPOB, 2011). Rapid expansion has diminished suitable land for oil palm and, thus venturing into peat area is inevitable. The Sarawak state possessed 1.7 million ha of peat but only 25% was planted with oil palm. This provides a great opportunity for expansion of the industry. However, planting oil palm in peat is challenging and full of limitations such as high acidity, inconsistent level of water table (Kamal and Abdullah, 2001), peat subsidence, poor palm anchorage and lastly vulnerable to insect pests (Cheng and Gurmit, 2008). Peat soil is full with partially decomposed organic material, which is a natural habitat of subterranean termites. Most termite species are beneficial insects such as scavengers and wood feeder that help maturing the peat and breaking down the organic material to nutrients available for plant absorption.

Termites are social insects that lives in an organised community comprised of different castes (Pearce, 1997; Lee and Wood, 1971; Harris, 1969). There are classified in 7 families; namely Mastotermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae, Serritermitidae and Termitidae (Engel and Krishna 2004). The family of Rhinotermitidae especially *Coptotermes* is the major pests in

America, Europe and Asia (Pearce, 1997). *Coptotermes curvignathus* was identified as a major pest in a number of crops such as oil palm (Lim and Silek, 2001; Suharto *et al*., 1991; Wood, 1968), rubber (Harris, 1969), coconut (Khoo *et al*., 1991; Sudharto *et al*., 1991), *Acacia mangium* (Chey and Intachat, 2000) and other fruit trees such as mango (Khoo *et al*., 1991).

Coptotermes curvignathus is one of the few termite species reported that feeds on living tissue. Due to its feeding nature, many of the immature palms died when the spear region and the meristematic tissue inside the palm were being consumed. The infestation of oil palm was not limited to the immature palm but the mature palm was also affected (Lim and Silek, 2001; Sudharto *et al*., 1991; Wood, 1968). The aggressive feeding of *C. curvignathus* usually takes about 30-60 days to kill an immature palm while about 90 days for a mature palm. Due to the cryptic behaviour of the subterranean termite, the available symptom of oil palm infestation was limited to the construction of mud sheeting either on the trunk surface or in the spear region. This can be problematic because untimely curative measures mean the death of palm while, preventive measure cannot be carried out due to undetectable foraging tunnels.

In oil palm plantations, heavy dosages of chemical are applied only when an infested palm was detected. Insecticide was applied at the trunk and shoot, and sometimes drenching the whole palm was also observed (Bong and King, 2006) Moreover, diamond spraying was applied to the surrounding palm to prevent the pest from migrating to other palms. Since organochlorine chemical is banned, the commonly used chemicals such as chlopyrifos and friponil are able to kill the termite rapidly (Vargo and Parman, 2012). Heavy usage of insecticide was proven non economical and destructive to the environment and other beneficial termite, thus a more environmental friendly and target specific methods was adopted. The entomopathogenic fungi such as *Metarhizium anisopliae* var *anisopliae*, (Hoe *et al*., 2009), *Beauveria* spp. and *Pecilomyces* spp. were introduced but had limited success (Lim and Silek, 2001; Suharto *et al*., 1991). Baiting system incorporated with either slow acting toxicant, chitin inhibitor or insect growth regulator was used nowadays (Sajap *et al*., 2009; Sajap *et al*., 2000; Su, 1994; Su, 1991; Su *et al*., 1991; Su and Scheffrahn, 1990). It manipulates the feeding behaviour of termite, trophallaxis which the chemical will be passed from one to another and in times gradually eliminate the whole colony (Pearce, 1997).

The inconsistency of success in controlling the subterranean termite were attributed to a few factors such as high population of termite (Tamashiro *et al*., 1980), the extensive foraging area, the usage of wrong types of chemical in baiting station (Su *et al*., 1982) and the limited knowledge on foraging behaviour of the termite (Su *et al*., 1984). The inability to grasp the detail of their specific behaviour was due to insufficient understanding of their cryptic behaviour. Recent findings through modelling and simulation study such as foraging show that *Coptotermes formosanus* was moisture orientated (Su and Puche, 2003), affected by structural anomalies rather than food (Campora and Grace, 2001; Puche and Su, 2001), relationship of foraging efficiency towards the heterogeneity of landscape (Lee *et al*., 2008b; Lee *et* *al*., 2007a) while literature on foraging behaviour of *C. curvignathus* was limited.

Therefore, the objective of the study was

1) Verification of *Coptotermes curvignathus* via morphology and genetic markers
2) To determine the tunnelling activity of *Coptotermes curvignathus* in food present and absent arena.
3) To detect the presence or absence of *Coptotermes curvignathus* using baiting system surrounding an infested palm
4) To investigate the damage pattern and infestation of *Coptotermes curvignathus* in oil palm on peat soil

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BIODATA OF STUDENT

Chan Seow Phan was born in Ipoh, Perak, Malaysia on the 03 October 1984. He did his primary education at the Sekolah Kebangsaan Methodist A.C.S. Ipoh, Perak and continued his secondary schooling at Sekolah Menengah Methodist A.C.S. Ipoh Perak where he obtained his Penilaian Menengah Rendah (PMR), Sijil Peperiksaan Malaysia (SPM) and Sijil Tinggi Pelajaran Malaysia (STPM). He started tertiary education at Universiti Putra Malaysia and obtained a Second Class Upper B. Sc. Degree in Bioindustry in 2008. His intended academic interest in the future in pursuing research on entomology.

The distance matrix between *Coptotermes curvignathus* sample sequence and NCBI database sequence

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	96	95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	96	95	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	97	95	99	99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	97	95	99	99	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	96	95	99	99	99	99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	97	95	99	99	100	100	99	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	96	95	99	99	99	99	99	99	-	-	-	-	-	-	-	-	-	-	-	-	-
10	96	95	99	99	99	99	99	99	100	-	-	-	-	-	-	-	-	-	-	-	-
11	96	94	99	99	99	99	99	99	98	99	-	-	-	-	-	-	-	-	-	-	-
12	94	93	97	97	97	97	98	97	96	98	97	-	-	-	-	-	-	-	-	-	-
13	94	95	97	97	97	97	97	97	96	96	96	95	-	-	-	-	-	-	-	-	-
14	95	95	96	96	97	97	97	97	96	96	96	95	98	-	-	-	-	-	-	-	-
15	95	95	95	95	96	96	95	96	96	96	95	94	97	97	-	-	-	-	-	-	-
16	96	96	96	96	96	96	96	96	96	96	95	94	97	98	99	-	-	-	-	-	-
17	96	96	96	96	96	96	96	96	96	96	95	94	97	98	99	100	-	-	-	-	-
18	95	95	96	96	96	96	96	96	96	96	95	94	97	98	99	99	99	-	-	-	-
19	95	95	96	96	96	96	96	96	96	96	95	94	97	98	99	99	99	100	-	-	-
20	96	96	96	96	96	96	96	96	96	96	95	94	97	98	99	100	100	99	99	-	-
21	96	96	96	96	96	96	96	96	96	96	95	94	97	98	99	100	100	99	99	100	-

APPENDIX 2

TUNNEL LENGTH AND TUNNEL INITIATION FOR FOOD PRESENT AND FOOD ABSENT ARENA

Direction	Replication	Tunnel length (cm)		Tunnel initiation	
		Food absent	Food present	Food absent	Food present
North	1	85.7	375.92	0	2
	2	228.89	307.07	1	0
	3	253.15	385.09	0	1
	4	43.34	397.18	0	1
	5	0	171.61	1	1
	6	103.15	446.96	1	1
	7	65.7	307.66	0	1
	8	166.37	465.56	1	1
	9	81.4	239.37	3	2
	10	90.3	394.1	1	1
	11	150.05	329.84	1	2
	12	158.80	464.27	0	0
	13	111.39	203.52	0	1
	14	270.50	225.37	0	1
Northeast	1	118.87	431.22	1	0
	2	104.63	355.1	0	2
	3	230.25	182.39	0	1
	4	225.34	248.04	0	3
	5	0	263.63	0	3
	6	100.85	287.75	1	2
	7	161.86	85.69	0	3
	8	87.03	16.23	2	1
	9	62.05	303.12	0	2
	10	248.1	146.9	0	2
	11	92.08	247.57	0	1
	12	211.41	342.54	1	0
	13	41.91	214.6	0	2
	14	77.03	331.23	1	0
East	1	114.99	141.17	0	1
	2	318.51	202.14	2	1
	3	106.04	188.86	0	1
	4	106.19	243.79	0	1
	5	84.44	220.11	0	1
	6	177.5	97.3	0	1
	7	0	130.26	1	0
	8	153.25	184.43	0	1
	9	125.58	293.56	4	1
	10	44.87	124.71	2	1
	11	99.83	193.04	1	0
	12	182.21	216.98	1	2
	13	204.37	100.95	0	0

	14	180.5	134.44	1	0
Southeast	1	156.34	294.79	1	1
	2	133.45	404.39	0	0
	3	505.49	435.96	0	1
	4	49.5	131.26	0	2
	5	31.33	341.35	0	1
	6	169.28	248.32	1	3
	7	194.13	209.73	0	3
	8	196.97	315.06	0	0
	9	7.53	309.17	1	1
	10	59.97	184.95	1	2
	11	49.34	422.63	2	1
	12	190.86	212.37	0	0
	13	83.52	103.22	0	2
	14	0	83.54	0	0
South	1	235.26	125.48	1	1
	2	245.91	241.84	1	0
	3	241.45	379.21	0	0
	4	163.14	253.7	0	3
	5	68.88	290.63	1	3
	6	272.73	382.99	1	3
	7	182.58	207.82	0	1
	8	274.55	174.17	0	2
	9	84.75	264.13	2	1
	10	205.73	162.63	1	0
	11	122.42	342.54	2	1
	12	158.26	355.95	2	1
	13	76.9	327.06	0	1
	14	230.69	229.44	1	1
Southwest	1	257.14	393.07	1	1
	2	381.46	205.06	0	2
	3	263.08	425.53	0	0
	4	89.26	209.89	0	1
	5	297.47	263.69	1	2
	6	201.44	257.58	0	1
	7	76.55	157.35	1	1
	8	86.69	150.63	1	1
	9	83.24	240.8	0	2
	10	95.19	5.88	2	1
	11	200.76	255.32	2	1
	12	96.73	104.27	0	1
	13	233.37	11.85	1	0
	14	221.65	297.7	2	1
West	1	151.76	115.06	1	0
	2	105.91	219.85	1	1
	3	622.78	445.7	0	0
	4	70.76	310.02	1	0
	5	417.75	324.84	0	0
	6	0	263.67	1	1
	7	209.54	0	1	2

	8	157.34	0	2	0
	9	18.49	41.11	1	1
	10	269	162.25	2	2
	11	25.62	318.12	1	1
	12	208.73	157.74	1	0
	13	125.1	0	2	2
	14	292.19	235.05	0	2
Northwest	1	276.57	234.6	0	0
	2	303.51	144.29	0	2
	3	572	351.83	0	0
	4	100.66	305.44	0	1
	5	287.81	231.82	1	1
	6	70.38	153.3	0	0
	7	48.78	0	2	1
	8	0	0	0	3
	9	66.74	122.7	0	4
	10	181.55	264.65	0	0
	11	175.88	314.43	1	2
	12	0	210.72	1	2
	13	153.92	146.57	1	2
	14	116.01	139.81	1	0

APPENDIX 3

LENGTH OF EACH TUNNEL BRANCHING IN FOOD ABSENT ARENA

Food absent arena	Tunnel Branching in length (cm)			Tunnel Branch in Percentage		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
1	652.73	397.47	13.53	40.93	24.92	0.85
2	566.37	236.63	590.13	40.65	16.99	42.36
3	0	0	829.62	0	0	100
4	242.19	54.71	1206.18	16.11	3.64	80.25
5	439.28	9.04	1035.19	29.61	0.61	69.78
6	755.34	508.42	113.17	54.86	36.92	8.22
7	537.49	275.85	273.52	29.7	15.24	15.11
8	650.9	356.85	1239.55	28.96	15.88	55.16
9	1363.8	380.1	113.32	44.4	12.38	3.69
10	1171.82	473.87	556.54	40.52	16.38	19.24
11	1469.86	555.07	549.51	43.46	16.41	16.25
12	636.34	323.13	483.12	36.87	18.72	27.99
13	755.07	187.44	703.78	34.4	8.54	32.06
14	569.11	170	232.56	51.53	15.39	21.06

APPENDIX 4

LENGTH OF EACH TUNNEL BRANCHING IN FOOD PRESENT ARENA

Food present arena	Tunnel Branching in length (cm)			Tunnel Branch in Percentage		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
1	557.51	279.94	3087.15	12.33	6.19	68.28
2	1026.81	508.74	2519.56	22.01	10.91	54.01
3	421.14	35.52	3396.79	10.45	0.88	84.26
4	207.9	71.96	2298.84	7.74	2.68	85.54
5	1182.24	448.18	1452.7	33.42	12.67	41.06
6	1683.77	365.33	1021.67	54.83	11.9	33.27
7	835.7	125.88	914.67	38.51	5.8	42.15
8	1716.77	515.32	274.96	68.48	20.55	10.97
9	689.97	538.44	212.67	44.25	34.53	13.64
10	1131.13	221.75	1006.04	46.73	9.16	41.56
11	781.15	285.91	424.44	44.23	16.19	24.03
12	1309.39	578.07	1577.73	36.06	15.92	43.45
13	1176.1	691.29	796.19	40.92	24.05	27.7
14	338.04	258.43	907.43	14.97	11.44	40.18

APPENDIX 5

ANOVA TABLE FOR TUNNEL LENGTH IN EACH DIRECTION IN NO FOOD ARENA

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	7	78694.457	11242.065	0.88	0.5253
Error	104	1329129.793	12780.094		
Total	111	1407824.249			
Direction	7	78694.45669	11242.06524	0.88	0.5253ns

CV = 72.4665

ns = Non significant

APPENDIX 6

CHI SQUARE FOR TUNNEL INITIATION IN NO FOOD ARENA

Direction	Frequency	Percentage	Test Percentage	Cumulative Frequency	Cumulative Percentage
North	9	11.69	12.50	9	11.69
Northeast	6	7.79	12.50	15	19.48
East	12	15.58	12.50	27	35.06
Southeast	6	7.79	12.50	33	42.86
South	12	15.58	12.50	45	58.44
Southwest	11	14.29	12.50	56	72.73
West	14	18.18	12.50	70	90.91
Northwest	7	9.09	12.50	77	100.00

APPENDIX 7

ANOVA TABLE FOR TUNNEL BRANCHING IN LENGTH IN NO FOOD ARENA

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	2	1290070.090	645035.045	5.45	0.0082
Error	39	4613660.657	118298.991		
Total	41	5903730.748			
Tunnel Branch	2	1290070.090	645035.045	5.45	0.0082**

CV = 66.6359

** Significant at $p \leq 0.01$

APPENDIX 8

ANOVA TABLE FOR TUNNEL BRANCHING IN PERCENTAGE IN NO FOOD ARENA

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	2	0.55974582	0.27987291	3.84	0.0300
Error	39	2.84227755	0.07287891		
Total	41	3.40202337			
Tunnel Branch	2	0.55974582	0.27987291	3.84	0.0300*

CV = 88.1125

* Significant at $p \leq 0.05$

APPENDIX 9

REGRESSION ANALYSIS USED TO DETERMINE THE DECREASING TUNNEL LENGTH EXCAVATED

Source	DF	Sum of square	Mean square	F value	Pr > F
Model	1	925554	925554	18.00	0.0081
Error	5	257035	51407		
Total	6	1182588			
Variable	DF	Parameter estimate	Standard error	T value	Pr > T
Intercept	1	987.774	116.573	8.47	0.0004**
Day	1	-34.775	8.19556	-4.24	0.0081**

$r^2 = 0.7827$

CV = 34.75

N = 7

** Significant at $p \leq 0.01$

APPENDIX 10

ANOVA TABLE FOR TUNNEL LENGTH IN EACH DIRECTION IN FOOD PRESENT ARENA

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	7	294273.728	42039.104	3.66	0.0014
Error	104	1195581.995	11495.981		
Total	111	1489855.723			
Direction	7	294273.7283	42039.1040	3.66	0.0014**

CV = 45.7159

** Significant at $p \leq 0.01$

APPENDIX 11

CHI SQUARE FOR TUNNEL INITIATION IN FOOD PRESENT ARENA

Direction	Frequency	Percentage	Test Percentage	Cumulative Frequency	Cumulative Percentage
North	15	11.72	12.50	15	11.72
Northeast	22	17.19	12.50	37	28.91
East	11	8.59	12.50	48	37.50
Southeast	17	13.28	12.50	53	50.78
South	18	14.06	12.50	83	64.84
Southwest	15	11.72	12.50	98	76.56
West	12	9.38	12.50	110	85.94
Northwest	18	14.06	12.50	128	100.00

APPENDIX 12

ANOVA TABLE FOR TUNNEL BRANCHING IN LENGTH IN FOOD PRESENT ARENA

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	2	8019520.43	4009760.21	9.16	0.0005
Error	39	17081446.42	437985.81		
Total	41	25100966.85			
Tunnel Branch	2	8019520.427	4009760.213	9.16	0.0005**

CV = 73.3917

** Significant at $p \leq 0.01$

APPENDIX 13

ANOVA TABLE FOR TUNNEL BRANCHING IN PERCENTAGE IN FOOD PRESENT ARENA

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	2	0.83601849	0.41800924	9.87	0.0003
Error	39	1.65155654	0.04234760		
Total	41	2.48757502			
Tunnel Branch	2	0.83601849	0.41800924	9.87	0.0003**

CV = 64.5284

** Significant at $p \leq 0.01$

APPENDIX 14

ANOVA TABLE FOR TUNNEL LENGTH IN FOOD PRESENT AND ABSENT ARENAS

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	8	465706.945	58213.368	4.51	<.0001
Error	215	2777340.900	12917.865		
Total	223	3243047.845			
Direction	7	120339.0725	17191.2961	1.33	0.2369ns
Food source	1	345367.8725	345367.8725	26.74	<.0001**

CV = 58.2055

ns = Non significant

** Significant at $p \leq 0.01$

APPENDIX 15

CHI SQUARE FOR TUNNEL INITIATION FOR DIRECTION IN FOOD PRESENT AND ABSENT ARENAS

Direction	Frequency	Percentage	Test Percentage	Cumulative Frequency	Cumulative Percentage
North	24	11.71	12.50	24	11.71
Northeast	28	13.66	12.50	52	25.37
East	23	11.22	12.50	75	36.59
Southeast	23	11.22	12.50	98	47.80
South	30	14.63	12.50	128	62.44
Southwest	26	12.68	12.50	154	75.12
West	26	12.68	12.50	180	87.80
Northwest	25	12.20	12.50	205	100.00

APPENDIX 16

CHI SQUARE FOR AMOUNT OF TUNNEL INITIATION IN FOOD PRESENT AND ABSENT ARENA

Food source	Frequency	Percentage	Test Percentage	Cumulative Frequency	Cumulative Percentage
No Food	77	37.65	50	77	37.56
Food	128	62.44	50	205	100.00

APPENDIX 17

ANOVA TABLE FOR TUNNEL BRANCHING IN LENGTH IN FOOD PRESENT AND ABSENT ARENAS

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	31	17199067.5500	554808.6300	1.70	0.0440
Error	52	16927840.9600	325535.4000		
Total	83	34126908.5100			
Food	1	3122210.9160	3122210.9160	9.59	0.0031**
Rep	13	1477941.1300	113687.7790	0.35	0.9793
Food* Rep	13	3289324.9910	253024.9990	0.78	0.6796ns
Tunnel	2	6918703.8960	3459351.9480	10.63	0.0001**
Food*Tunnel	2	2390886.6210	1195443.3100	3.67	0.0322ns
Food	1	3122210.9160	3122210.9160	12.34	0.0038**
Rep	13	1477941.130 0	113687.779 0	0.45	0.9188

CV = 80.4791

ns = Non significant

** Significant at $p \leq 0.01$

APPENDIX 18

ANOVA TABLE FOR TUNNEL BRANCHING IN PERCENTAGE IN FOOD PRESENT AND ABSENT ARENAS

Source	DF	Sum of square	Mean square	F value	Pr> F
Model	31	1.7407	0.0561	0.70	0.8519
Error	52	4.1521	0.0798		
Total	83	5.8928			
Food	1	0.0032	0.0032	0.04	0.8398ns
Rep	13	0.2326	0.0178	0.22	0.9974
Food* Rep	13	0.1090	0.0083	0.11	1.0000ns
Tunnel	2	1.3709	0.6854	8.58	0.0006**
Food*Tunnel	2	0.0248	0.0124	0.16	0.8565ns
Food	1	0.0032	0.0032	0.39	0.5417ns
Rep	13	0.0178	0.0178	2.13	0.0927

CV = 90.3825

ns = Non significant

** Significant at $p \leq 0.01$

APPENDIX 19

TREND ANALYSIS OF MONTHLY RAINFALL AND PERCENTAGE INFESTATION IN SITE 1 AND SITE 2 IN SEMANOK OIL PALM PLANTATION.

Source	DF	Sum of square	Mean square	F value	Pr > F
Model	1	169.40	169.140	1.13	0.3227
Error	7	1047.478	149.639		
Total	8	1216.88222			
Variable	DF	Parameter estimate	Standard error	T value	Pr > T
Intercept	1	28.0752	6.8596	4.09	0.0046
rainfall	1	0.01159	0.01090	1.06	0.3227ns

$r^2 = 0.1392$

CV = 36.03

N = 9

Ns = non significant

APPENDIX 20

MONTHLY RAINFALL DATA FROM APRIL 2010 TILL MARCH 2012 IN TANIKU 1, TANIKU 2, SUNGAI BALIM AND SUNGAI TRUS OIL PALM PLANTATIONS.

	Rainfall (mm)			
Months	Taniku 1	Taniku 2	Sungai Balim	Sungai Trus
April 2010	257.50	257.50	192.00	233.00
May 2010	245.00	245.00	205.00	344.30
Jun 2010	348.50	348.50	243.00	272.50
July 2010	330.00	330.00	264.00	514.66
August 2010	359.00	359.00	369.00	404.50
September 2010	405.50	405.50	456.00	653.70
October 2010	278.00	278.00	268.00	514.00
November 2010	354.50	354.50	353.00	620.00
December 2010	346.00	346.00	316.00	796.00
January 2011	571.00	571.00	487.00	1046.50
February 2011	392.00	392.00	139.00	144.95
March 2011	345.00	345.00	107.00	278.03
April 2011	334.00	334.00	327.00	543.00
May 2011	274.50	274.50	258.00	223.90
June 2011	352.50	352.50	285.00	346.95
July 2011	174.50	174.50	132.00	137.33
August 2011	156.50	156.50	189.00	276.30
September 2011	259.50	259.50	226.00	166.50
October 2011	233.50	233.50	180.00	283.00
November 2011	217.50	217.50	261.00	257.50
December 2011	293.00	293.00	413.00	301.00
January 2012	373.50	373.50	250.00	400.00
February 2012	322.00	322.00	226.00	136.00
March 2012	240.50	240.50	178.00	231.00

APPENDIX 21

INFESTATION INCIDENCE IN SUNGAI TRUS ESTATE FROM APRIL 2010-MARCH 2012

Months	Infestation incident Sungai Trus Estate		
	Trunk	Spear	Basal
April 2010	62	33	0
May 2010	86	16	0
Jun 2010	101	18	0
July 2010	73	30	0
August 2010	53	13	0
September 2010	38	7	0
October 2010	66	10	0
November 2010	98	23	0
December 2010	146	26	0
January 2011	102	30	0
February 2011	46	13	0
March 2011	66	24	0
April 2011	48	40	0
May 2011	37	5	0
June 2011	65	9	0
July 2011	148	28	0
August 2011	63	14	0
September 2011	69	71	0
October 2011	104	42	0
November 2011	41	17	0
December 2011	58	17	0
January 2012	169	30	0
February 2012	47	15	0
March 2012	63	19	0

APPENDIX 22

INFESTATION INCIDENCE IN SUNGAI BALIM ESTATE FROM APRIL 2010-MARCH 2012

Months	Infestation incident Sungai Balim Estate		
	Trunk	Spear	Basal
April 2010	159	25	0
May 2010	243	45	0
Jun 2010	206	36	0
July 2010	198	22	0
August 2010	258	33	0
September 2010	175	24	0
October 2010	180	38	0
November 2010	259	38	0
December 2010	345	54	0
January 2011	359	62	0
February 2011	325	43	0
March 2011	265	28	0
April 2011	253	30	0
May 2011	322	30	0
June 2011	278	27	0
July 2011	235	25	0
August 2011	204	21	0
September 2011	266	35	0
October 2011	239	35	0
November 2011	361	38	0
December 2011	310	36	0
January 2012	314	28	0
February 2012	213	15	0
March 2012	204	47	0

APPENDIX 23

INFESTATION INCIDENCE IN TANIKU 1 ESTATE FROM APRIL 2010-MARCH 2012

Month	Infestation incident Taniku 1 Estate		
	Trunk	Spear	Basal
April 2010	248	144	0
May 2010	315	176	0
Jun 2010	282	213	0
July 2010	223	149	0
August 2010	287	93	0
September 2010	166	78	0
October 2010	273	107	0
November 2010	380	118	0
December 2010	402	96	0
January 2011	313	75	0
February 2011	338	46	0
March 2011	235	46	0
April 2011	293	61	0
May 2011	220	55	0
June 2011	212	88	0
July 2011	199	73	0
August 2011	112	58	0
September 2011	379	101	0
October 2011	264	73	0
November 2011	371	84	0
December 2011	371	64	0
January 2012	311	57	0
February 2012	346	56	0
March 2012	355	38	0

APPENDIX 24

INFESTATION INCIDENCCE IN TANIKU 2 ESTATE FROM APRIL 2010-MARCH 2012

Months	Infestation incident Taniku 2 Estate		
	Trunk	Spear	Basal
April 2010	32	127	0
May 2010	52	97	0
Jun 2010	48	91	0
July 2010	70	101	0
August 2010	51	86	0
September 2010	68	98	0
October 2010	52	44	0
November 2010	65	65	0
December 2010	92	86	0
January 2011	89	53	0
February 2011	65	31	0
March 2011	64	22	0
April 2011	54	20	0
May 2011	35	29	0
June 2011	46	26	0
July 2011	67	20	0
August 2011	54	15	0
September 2011	35	22	0
October 2011	6	0	0
November 2011	54	28	0
December 2011	42	18	0
January 2012	24	11	0
February 2012	31	1	0
March 2012	45	0	0

APPENDIX 25

TREND ANALYSIS OF MONTHLY RAINFALL AND TOTAL INFESTATION INCIDENCES IN SUNGAI TRUS OIL PALM PLANTATION.

Source	DF	Sum of square	Mean square	F value	Pr > F
Model	1	1881.51	1881.51	1.04	0.3193
Error	22	39867	1812.16		
Total	23	41749			
Variable	DF	Parameter estimate	Standard error	T value	Pr > T
Intercept	1	84.69	17.32	4.89	<0.0001
rainfall	1	0.04	0.04	1.02	0.3193ns

$r^2 = 0.0451$

CV = 42.59

N = 24

Ns = non significant

APPENDIX 26

TREND ANALYSIS OF MONTHLY RAINFALL AND TOTAL INFESTATION INCIDENCES IN SUNGAI BALIM OIL PALM PLANTATION.

Source	DF	Sum of square	Mean square	F value	Pr > F
Model	1	6785.996	6785.996	1.61	0.2184
Error	22	92986	4226.62		
Total	23	99772			

Variable	DF	Parameter estimate	Standard error	T value	Pr > T
Intercept	1	245.41	38.40	6.39	<0.0001
rainfall	1	0.17354	0.13696	1.27	0.2184ns

r^2 = 0.068

CV = 22.33

N = 24

Ns = non significant

APPENDIX 27

TREND ANALYSIS OF MONTHLY RAINFALL AND TOTAL INFESTATION INCIDENCES IN TANIKU 1 OIL PALM PLANTATION.

Source	DF	Sum of square	Mean square	F value	Pr > F
Model	1	4381.7733	4381.7733	0.56	0.4627
Error	22	172518	7841.707		
Total	23	176899			

Variable	DF	Parameter estimate	Standard error	T value	Pr > T
Intercept	1	327.277	68.714	4.76	<0.0001
rainfall	1	0.159	0.21318	0.75	0.4627ns

$r^2 = 0.0248$

CV = 23.49

N = 24

Ns = non significant

APPENDIX 28

TREND ANALYSIS OF MONTHLY RAINFALL AND TOTAL INFESTATION INCIDENCES IN TANIKU 2 OIL PALM PLANTATION.

Source	DF	Sum of square	Mean square	F value	Pr > F
Model	1	7430.530	7430.530	3.41	0.0782
Error	22	47891	2176.854		
Total	23	55321			

Variable	DF	Parameter estimate	Standard error	T value	Pr > T
Intercept	1	32.633	36.204	0.90	0.3772ns
rainfall	1	0.20752	0.11232	1.85	0.0782ns

$r^2 = 0.1343$

CV = 48.017

N = 24

Ns = non significant

BIODATA OF STUDENT

Chan Seow Phan was born in Ipoh, Perak, Malaysia on the 03 October 1984. He did his primary education at the Sekolah Kebangsaan Methodist A.C.S. Ipoh, Perak and continued his secondary schooling at Sekolah Menengah Methodist A.C.S. Ipoh Perak where he obtained his Penilaian Menengah Rendah (PMR), Sijil Peperiksaan Malaysia (SPM) and Sijil Tinggi Pelajaran Malaysia (STPM). He started tertiary education at Universiti Putra Malaysia and obtained a Second Class Upper B. Sc. Degree in Bioindustry in 2008. His intended academic interest in the future in pursuing research on entomology.